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NEWLY DISCOVERED
PHENOMENON
PRODUCED BY
STATIONARY SOUND-WAVES

BY
BERGEN DAVIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY IN THE FACULTY OF
PURE SCIENCE, COLUMBIA UNIVERSITY

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HENRY A. ROWLAND

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ON A NEWLY DISCOVERED PHENOMENON PRODUCED BY STATIONARY SOUND-WAVES.

BY BERGEN DAVIS.

IN the course of an investigation upon the action of stationary sound-waves, under certain conditions I have observed, that if a small cylinder which is closed at one end, is placed in a stationary sound-wave, it will not only arrange itself perpendicular to the wave, but will also move across it in a direction perpendicular to the stream-lines. The force producing this motion is of considerable magnitude, and it acts normally to the closed end of the cylinder, causing it to move in the direction of the closed end, *i. e.*, the closed end is driven towards the wall of the organ-pipe.

A short description of this phenomenon has already been published,¹ since which a more complete investigation has been in progress.

DESCRIPTION OF APPARATUS.

The stationary wave used was that obtained in a stopped organ-pipe when blown so as to produce its first overtone. Two nodes were thus obtained, one at the stopped end and the other near the mouth. A thin rubber diaphragm was inserted in the pipe at this node as shown at *d* in Fig. 1. I have found, as has been observed by Lord Rayleigh,² that a thin diaphragm at a node does not alter the intensity of the sound appreciably. This diaphragm kept the interior of the pipe free from any disturbances that might arise from blowing.

Two pipes were used in these experiments, a long one and a short one. A section of the longer pipe is shown in Fig. 1. The length of the pipe was 216 cm., from the mouth to the end. It was provided with a movable stop which could be placed at various

¹ Am. Journal of Science, Sept., 1900.

² Phil. Mag., Vol. XIV., p. 186, 1882.

positions as *A*, *C*, *I* and *H*. One side of the pipe from the diaphragm to the end was removed and a glass panel substituted for it. This arrangement made the whole of the interior of the pipe visible from the diaphragm to any position of the movable stop. A slit about 8 mm. wide, extending from near the diaphragm to near the end, was cut into the upper side of the pipe. This slit was

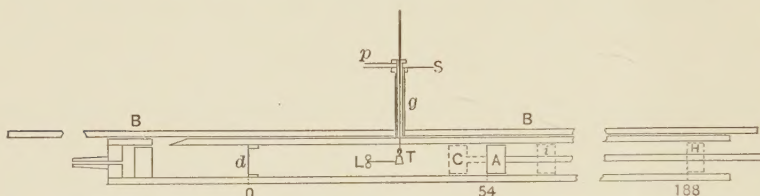


Fig. 1.

covered by a long wooden bar *B* of about 2.5 by 3 cm. in cross-section. The side of the pipe around this slit was lined with kid skin. The bar when pressed down upon this closed the slit and rendered the pipe air-tight. A glass tube *g*, carrying at the top a circular, graduated scale *s*, was inserted in the bar near its center. The torsion wire passed down this tube into the pipe. By this arrangement the torsion balance *T* could be moved along the pipe to any desired position.

The diaphragm was placed at 16 cm. from the lip, as this was found to be the position of the node. A centimeter scale was placed along the pipe, the zero being at the diaphragm, *i. e.*, the first node.

The readings along this scale will also represent distances along the stationary wave. The pipe was 6.7 cm. by 5.5 cm. in cross-section, the height of the mouth opening being 3 cm.

The shorter pipe may also be represented by Fig. 1, by considering the end of the pipe to be at stop *A*, and this stop immovable. This pipe was 67.8 cm. long from lip to stop and 5.3 cm. by 6.4 cm. in cross-section. The height of the mouth opening was 1.8 cm. The arrangements for torsional measurements were the same as those of the longer pipe. The diaphragm was placed at 15.8 cm. from the lip as this was found to be the position of the node.

A mercury manometer was used to regulate and compare the forces of blowing in the various experiments. It consisted of a U

tube of small bore containing mercury, which was inclined at an angle of 30° to the horizontal, so that the total difference in height of the mercury surfaces in the two branches was equal to the reading on a scale placed along one of the branches.

The torsion wire was No. .0035 platinum-silver. Its constant was determined by two methods: By observing the time of vibration of a suspended circular disc of known dimensions and mass; and by connecting the end of the torsion arm to the pointer of a chemical balance, and on turning the torsion head, observing the number of milligram necessary to bring the pointer back to zero.

The two methods gave the same result. The constant was such that a force of one dyne acting at the end of an arm one centimeter in length, attached to a wire one centimeter long produced a deflection of $.3^\circ$ of arc.

The cylinders, the force of whose tendency to move was to be measured, were of four sizes. Three of them were made from gelatine capsules such as are used for medical purposes. The other, the largest one, was made of stiff paper. The dimensions of the cylinders were as follows:

TABLE I.

	Dia. cm.	Area sq. cm.	Length cm.
No. 5.	.421	.14	1.3
No. 2.	.575	.26	3.1
No. 00.	.794	.495	3.1
Paper.	1.15	1.04	3.1

The hemispherical end of the capsule cylinder was removed, and a paper disc inserted in its stead, thus giving a flat end to the cylinder. The caps were removed and two or more joined end to end to form a cylinder of desired length.

EXPERIMENTS WITH ROTATING MILL.

A small mill was constructed by fastening four No. 00 capsule cylinders each 1.7 cm. long, on cardboard arms as shown in Fig. 2. The arms of the mill were each two centimeters long. The mill was mounted, by means of a glass pivot, upon a fine steel point which was fastened to the end of a long rod. By means of this

rod the mill could be carried to any desired part of the stationary wave. The shorter pipe which was used in this experiment was placed in a vertical position.

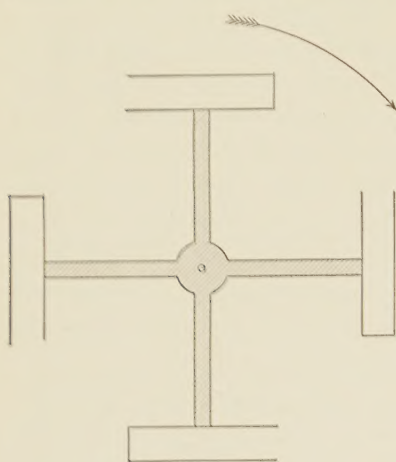


Fig. 2.

The rod bearing the mill was introduced through the stop at the lower end. The mill was thus enclosed in the pipe with its plane of rotation perpendicular to the stream-lines, *i. e.*, the vibrations were always perpendicular to the axes of the cylinders.

Matters being thus arranged when the pipe was blown, the mill rotated with a high velocity. The rate of rotation was greatest at the middle of the loop and it came to rest at the nodes.

A series of experiments were made to determine the variation of the rate of rotation with the position along the wave. A constant pressure of blowing was maintained throughout the experiments. The zero of the scale on the pipe is at the node at the diaphragm. A stroboscopic disc was used to count the rotations. The results of a number of experiments are given in the table below :

TABLE II.

Position along Pipe.	Relations per Second.	Position along Pipe.	Relations per Second.
0	0	27	9.00
4	.92	30	8.74
9	4.69	34	7.70
14	7.00	39	6.43
19	8.12	44	3.70
22	8.44	49	.77
25	8.80	52	.0

This table is plotted in the curve shown in Fig. 3. The ordinates are rates of rotation per second and the abscissæ are distances along pipe. The full line is the observed curve and the broken

line is a sine curve. The agreement of the observed curve and the sine curve is very close.

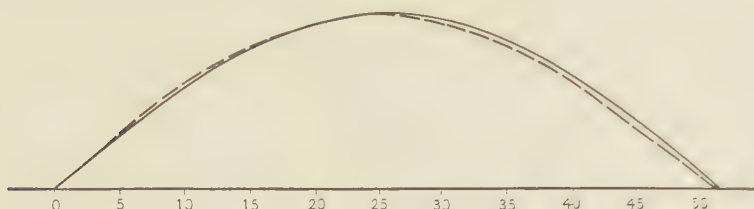


Fig. 3.

The force driving the cylinder across the pipe was measured by means of a torsion balance mounted in the longer pipe as shown in Fig. 1. Two cylinders L are mounted at the end of a cardboard arm, their plane being perpendicular to the pipe. They are placed a small distance apart to allow the vibration of the air between them. When the pipe was blown the cylinder moved towards the wall of the pipe and the torsion head was turned until the cylinders came back to their zero position. The amount of torsion was indicated by the pointer p on the scale s .

THE EFFECT OF AREA OF CROSS-SECTION OF THE CYLINDERS.

In making this investigation the mounted cylinders of various sizes were brought to the middle of the loop, the force being a maximum at that point. A table is given below of the degrees of torsion for the various cylinders. The sizes corresponding to the number of cylinders are given in Table I. The readings have all been reduced to the same area (1 sq. cm.) and the same length of arm. The manometer pressures are in centimeters of mercury.

It will be observed that for low pressure the small cylinders are affected the most. The No. 00 cylinders experience the largest force for moderate pressures as those near the pressure of maximum efficiency, while for the highest pressures the paper cylinder is most strongly affected. The No. 5 and No. 2 cylinders give almost identical results.

The shape of the body in the sound-wave also affects its behavior in a marked manner. Instead of the cylinders a hollow rectangular paralleliped was used, which was 30 mm. long, 20

TABLE III.

Degrees of Torsion.

Pressures.	No. 5.	No. 2.	No. oo.	Paper.
1½	20	22	10	8.6
2	66	64	89	46
3	198	215	320	176
4	362	306	410	354
5	460	409	550	620
6	530	500	690	630
7	644	610	750	745
8	715	714	830	820
9	811	780	920	969
10	862	834	1000	1090
11	898	891	1030	1220
12	925	907	1055	1318
13½	928	923	1080	1360
15	927	923	1060	1260
16	Overtone.			

mm. wide and 2 mm. thick. The area of the closed end was 40 sq. cm. This was placed in the sound-wave successively in two positions. (1) The 20 mm. edge was placed *perpendicular* to the directions of the stream-lines (position A). (2) The 20 mm. edge was placed *parallel* to the direction of the stream-lines (position B).

The results of the experiment are given in Table IV. *A* and *B* are the readings obtained at the given pressures in the two positions mentioned above. *A'* and *B'* are the same readings reduced to the

TABLE IV.

Degrees of torsion.

Pressures.	<i>A</i>	<i>B</i>	<i>A'</i>	<i>B'</i>	<i>C</i>
1	2.5	0	3.8	0	5
2	45	0	68	0	89
3	116	5	174	7.6	320
4	150	30	228	46	410
5	179	92	270	140	550
7	190	120	288	185	750
10	193	150	290	228	1000
12	198	160	300	245	1055
15	228	215	345	325	1060
17	255	256	436	436	

area of 1 sq. cm. and same length of arm used with No. 00 cylinders in Table III. Column *C* contains the results for No. 00 cylinders brought over from Table III. for comparison.

The force depends quite decidedly on the position of the paralleliped with reference to the stream-lines except in the case of large amplitudes, when the values approach and become equal just as the pipe passed over into the second overtone. By comparison with *C* it will be noticed that the rectangular shape gives much less effect than the cylindrical.

VARIATION OF THE FORCE ALONG THE STATIONARY WAVE.

The No. 2 capsule cylinders were used in these experiments. Two of them were fastened to the end of the arm of the torsion balance. The arm was 5.33 cm. long. The torsion balance was moved along the pipe and readings taken at intervals from near the diaphragm to the stopped end. The pipe was blown at the constant pressure of 3 cm. of mercury throughout. The note obtained at this pressure was quite free from overtones. The results of the experiments are given in Table V.

TABLE V.

Position along Pipe.	Torsions.	Sq. root of Torsion.	Position along Pipe.	Torsions.	Sq. root of Torsion.
0	0°	0	29	190°	13.8
6	36	6	32	173	13.1
11	79	8.9	35	145	12
16	148	12.1	39	102	10.1
21	185	13.6	42	73	8.6
25	194	13.9	48	25	5.
27	198	14.1	54	0	0

This table is plotted in Fig. 4. The abscissæ are positions along pipe and the ordinates are *square roots* of torsions. The full line is

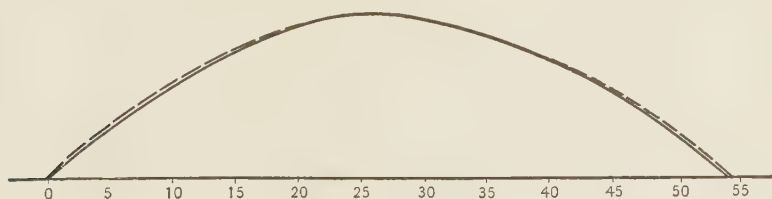


Fig. 4.

the observed curve and the broken line is a sine curve. The agreement of the two curves is quite close and indicates that the cylinders experience a force that is proportional to the square of the amplitude of vibration at any position.

EXPERIMENTS PERFORMED IN VARIOUS GASES.

The portion of the organ-pipe between the diaphragm and the stopped end forms a closed chamber which is kept free from all disturbances except the vibratory motion of air or gas. Various gases were introduced into this chamber and the force determined as before. The stationary wave that was formed was transmitted through two media: the gas back of the diaphragm and the air in front of it. Both pipes were used in these experiments, those with the shorter pipe are described first.

The stop was fixed and the length of the pipe could not be altered. When a dense gas as carbon dioxide was used, the pitch was lowered and the node was moved a little toward the stopped end. The pitch was raised when illuminating gas and hydrogen were used, and the node, at least in the case of the illuminating gas, was moved toward the mouth. The rise in pitch was quite noticeable with hydrogen. Measurements were made in the middle of the loop as before, care being taken to keep the pressure of blowing constant throughout the series of experiments.

The mean results of a number of experiments are given in the table below, the torsion readings in air as well as its density being taken as unity.

	Torsion Deflections.	Density of Gas.
Air	1.	1.
CO ₂	1.47	1.52
Illum. gas	.77	.75
Hydrogen	.064	.069

The force obtained is closely proportioned to the density of gas used. The above results were obtained when the pipe was blown at moderate pressures. The relation does not hold for all pressures, as will be shown later in this paper.

The stop of the shorter pipe was fixed, and the node, when the chamber contained air, was at the diaphragm. The densities of car-

bon dioxide and illuminating gas do not differ from air sufficiently to displace the node very much and the change of pitch obtained was approximately as should be expected. When hydrogen was used the pitch of the pipe was raised, but not at all in proportion to the inverse of the square root of its density. The pitch was such as to throw the node, had a simple wave been formed, just outside the mouth of the pipe. This would seem to indicate that a simple wave was not formed in this case, but that the mode of vibration was influenced in an indeterminate manner by the air space between the diaphragm and the mouth. The compartment of air between the diaphragm and the mouth possibly acted partially as a pipe having a stop at the position of the diaphragm. On account of the small density of the hydrogen its energy was inconsiderable compared to that of the air column, so that the tone obtained was a compromise between that natural to the air space outside the diaphragm and that natural to the hydrogen column within.

The pitch natural to the pipe with a stop at the position of the diaphragm is about 330 vibrations per second, while that natural to the hydrogen column behind the diaphragm would have been above 1,200 vibrations per second. This would seem to affirm that the characteristic pitch was largely determined by the air column in front of and not by the hydrogen column back of the diaphragm.

The longer pipe was constructed at the suggestion of Dr. F. L. Tufts for the purpose of overcoming these difficulties. This pipe had a movable stop, which was placed so as to give the same note as the shorter pipe, and then the diaphragm was adjusted to the node. The shorter pipe was used as a standard of pitch. On introducing carbon dioxide the stop was moved up until the pipe spoke in unison with the shorter one. In the case of illuminating gas or hydrogen the stop was moved back until unison was obtained. The positions of the stop were: for CO_2 , at 45 cm.; for air, at 54 cm.; for illuminating gas, at 62 cm., and for hydrogen, at 188 cm. from the diaphragm. These distances are nearly equal to one-half of the length of the stationary wave formed in each case. This arrangement made the conditions at the mouth and diaphragm constant for all the gases. The form of the exterior wave was not altered.

The efficiency curves of the organ-pipe for the gases were obtained by this arrangement, the torsion balance being moved so as to be in the middle of the loop of the stationary wave in all cases. The pipe was first blown at low pressure, and then the pressure was increased until it passed over into the next overtone. Table VI. contains the results of the experiments with various gases. The range of pressure of blowing in the case of hydrogen was so small that it was necessary to use a water manometer and afterward reduce the pressure to the corresponding mercury manometer readings. The torsion balance carried two No. 00 cylinders each 3.1 cm. long.

TABLE VI.

*Degrees of Torsion.**Hydrogen.*

Pressure.	Air.	Illum. gas.	CO ₂ .	Pres.	Torsion.
1	9	5	12	1.22	1.3
1½	69	45	90	1.47	3.8
2	195	120	290	1.62	10.9
2½	400	275	530	1.76	15.
3	510	365	690	1.91	26.
4	760	530	880	2.06	34.
5	920	670	1100	2.20	53.
6	1120	875	1170	2.41	64.
7	1230	1140	1200	2.50	overtone.
8	1250	1160	1220		
9	1260	1240	1210		
10	1270	1260	1230		
11	1290	1260	1230		
12	1320	1210	1250		
13	1470	1130	1280		
14	1500	overtone.	1260		
15	1570		1250		
16	overtone.		1350		
17			1520		
18			1560		
19			1560		
21			1500		
22			overtone.		

This table is plotted in Fig. 5, with pressures of blowing as ordinates and the square roots of torsion as abscissæ. It will be shown later that the amplitude of vibration is proportional to the square root of the force acting on the cylinders, hence the curves

obtained represent the relation between the pressures of blowing and the amplitude of vibration of the gas particles in the middle of the loop.

As a result of some experiment conducted by Dr. F. L. Tufts, it has been found that the cube of the velocity of efflux of air from the slit of an organ-pipe is approximately proportional to the square of the pressure. The energy of an escaping jet of air is also proportional to the cube of the velocity, hence the energy delivered to the pipe is proportional to the square of the pressure of blowing. The energy contained in the vibrating air is proportional to the square of the amplitude, consequently the torsions represent the energy converted into sound.

The curves of relation between torsions and squares of pressures plotted in Fig. 6, are the efficiency curves of the organ-pipe.

The pressure of maximum efficiency is indicated by the ordinates of the points of tangency of the tangents to the curves through the origin. This pressure was found to be nearly the same for all gases, being somewhat less for hydrogen. In the case of carbon dioxide, air and illuminating gas it was about 2.3 cm. of mercury. The torsions obtained at this pressure are given in the table below, the values for air as well as its density being taken as unity.

This is nearly the same result obtained with the shorter pipe.

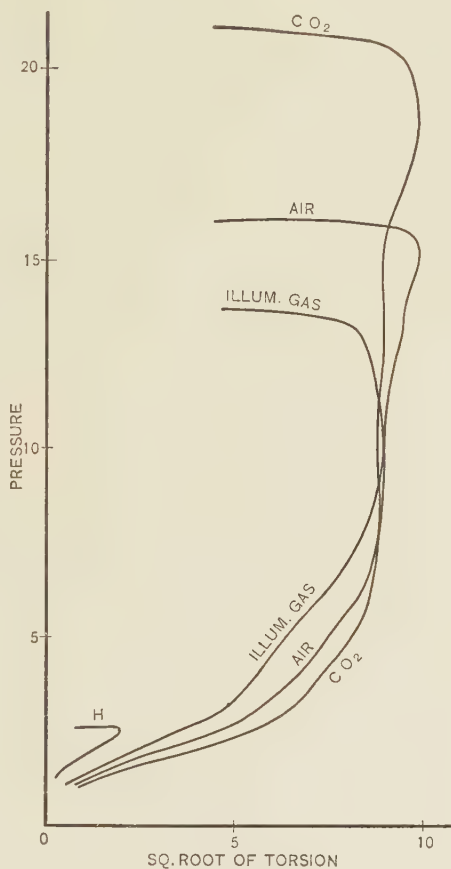


Fig. 5.

TABLE VII.

	Torsions.	Density of Gas.
Air	1.	1.
CO ₂	1.53	1.52
Illum. gas	.71	.75
Hydrogen	.153	.069



Fig. 6.

In the experiments the results of which are given in Table VI., the pressure was increased from zero until the note passed over into the next overtone. The pressure at which the second overtone was obtained was not sharply defined. At a high pressure the tone was in an unstable condition, so that when the finger was brought near the mouth of the pipe, the equilibrium was destroyed and the second overtone obtained. The pressure at which the second overtone appeared varied with the gas. The length of the pipe varied inversely as the density of the gas, so this shows the well-known fact that the longer a vibrating column, the more easily it breaks into shorter waves. The hydrogen wave being very long but a small pressure was necessary to force the next overtone.

The rates of rotation of the mill previously mentioned were also taken in the various gases. The shorter pipe was again used for this purpose. It was placed vertically and the mill introduced from below as before. The pressure of blowing was kept constant throughout the experiments. The mean results obtained are given below, the rate of rotation in air as well as its density being taken as unity.

Air.	Illum. Gas.	CO ₂ .	Hydrogen.
1	1	1.04	.59

The rate is apparently constant for all gases, although the force acting on the mill to produce this rotation is proportional to the density of the gas. This can be explained by the circumstance that the resistance to motion is also proportional to the density. The deviation from this result in the case of hydrogen is probably due to the fact that the friction of the supporting pivot was not an inconsiderable quantity compared to the total resistance experienced by the cylinders, and this factor is proportionately larger in the case of hydrogen.

DISCUSSION.

This phenomenon is another instance of the relation between pressure, density and velocity of a fluid first expressed analytically by Daniel Bernouilli.¹ A fluid in motion is less dense than the same fluid at rest. The air within the small cylinder remains nearly at rest, while that without is in rapid motion. The air on the outside is less dense than that within the cylinder. The force exerted is due to the difference in density and pressure on the two sides of the closed end of the cylinder. It is evident from the formula deduced below, that if the force is measured in absolute units then a value for the velocity and amplitude may be found.

The relation between the velocity, pressure, and density of a fluid may be expressed by Bernouilli's equation since for this case the average state of the fluid only is under consideration.

$$\int \frac{dp}{\rho} = R - \frac{1}{2}u^2.$$

¹ Hydrodynamica, Argentorati, 1728.

R is the potential due to external forces and is negligible in this case; hence

$$\int \frac{dp}{\rho} = -\frac{1}{2}u^2.$$

The adiabatic gas relation gives $p = C\rho^\gamma$, where C is a constant and γ is the ratio of the specific heat at constant pressure to that at constant volume.

$$C^{\frac{1}{\gamma}} \int p^{-\frac{1}{\gamma}} dp = \frac{1}{2}u^2.$$

$$\left[\frac{\gamma}{\gamma-1} C^{\frac{1}{\gamma}} p^{\frac{\gamma-1}{\gamma}} \right]_1^2 = \left[-\frac{1}{2}u^2 \right]_1^2.$$

$$\text{Let } \frac{\gamma-1}{\gamma} = n \quad \text{and } A = \frac{\gamma}{\gamma-1} C^{\frac{1}{\gamma}}$$

$$A(p_2^n - p_1^n) = -\frac{1}{2}(u_2^2 - u_1^2)$$

$$\frac{1}{n} \cdot \frac{p_2}{\rho} \left[1 - \left(1 - \frac{p_2 - p_1}{p_2} \right)^n \right] = -\frac{1}{2}(u_2^2 - u_1^2)$$

Expanding and neglecting all powers above the first, since $\frac{p_2 - p_1}{p_2}$ is a very small quantity, the equation reduces to, $u_1^2 - u_2^2 = 2 \frac{p_2 - p_1}{\rho}$.

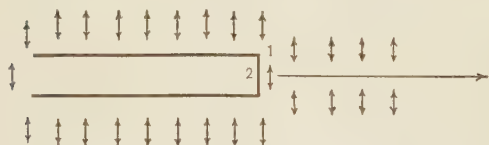


Fig. 7.

The cylinder is in the moving air as shown in Fig. 7. u_1 represents the velocity of the air outside the cylinder, and u_2 represents the velocity within the cylinder next to the closed end, while p_2 and p_1 are the pressures on the two sides of the closed end. If the air within the cylinder is at rest u_2 is zero, hence

$$u_1^2 = 2 \frac{p_2 - p_1}{\rho} \quad (1)$$

The constant of the torsion wire as previously given was $.3^\circ$ per dyne of force. The wire was 16 cm. long and the arm was 4.82 cm.

in length. The maximum deflection obtained was 1570° , hence the force was 68.26 dynes per square centimeter.

The force experienced by the cylinders is the mean of all the instantaneous values due to the velocity of the air at any instant. The force is proportional to the square of the velocity, hence the mean force will not directly give the mean velocity in equation (1).

The force F at any instant is equal to $\frac{1}{2}\rho u^2$, where u is the instantaneous velocity. Let A be the maximum displacement, and x any displacement at time t .

$$x = A \cos nt.$$

$$n = \frac{2\pi}{T},$$

where T is the periodic time.

$$\frac{dx}{dt} = u = -An \sin nt.$$

Also

$$\frac{\int F dt}{\int dt} = p_2 - p_1,$$

the mean force experienced by the cylinders.

Therefore :

$$\frac{\int F dt}{\int dt} = \frac{\frac{1}{2}\rho \int n^2 A^2 \sin^2 nt dt}{\int dt}.$$

The limits of integration are 0 and $\frac{1}{2}T$; hence,

$$p_2 - p_1 = \rho A^2 \frac{\pi^2}{T}$$

and

$$A = \frac{T}{\pi} \sqrt{\frac{p_2 - p_1}{\rho}}.$$

The frequency of the pipe when blown at high pressure was 338 per second.

Therefore :

$$A = .216 \text{ cm.}$$

The total excursion of the particles was $2A = .432 \text{ cm.}$

This must be a minimum value, that is less than the real value as the investigation above assumes that the air within the cylinder is at rest, and that there is no friction between the surface of the cylinder and the vibrating air. The effect of such friction would be to decrease the velocity and surround the cylinder with a skin of air of little greater density.

Among the methods that have been devised to determine the amplitude of vibration in a stationary wave, that of Raps¹ might be mentioned. He measured the change in density at the node of an organ-pipe by a rather complex mechanical method and deduced the amplitude from such measurements. He obtained an amplitude of .34 cm., the pipe speaking its fundamental of 184 vibrations per second. The force that might have been obtained had small cylinders been used would have been 50.25 dynes per sq. cm. This does not differ greatly from the maximum force obtained in the experiments above described, although from the very nature of the investigation accurate comparison of results is not possible.

A consideration of the curves of efficiency in Fig. 6 shows that the pressure of maximum efficiency for carbon dioxide, illuminating gas and air is nearly the same, also by Table VII. the force at this pressure is proportional to the density of the gas. This confirms experimentally the statement of Lord Kelvin² in his letters to Guthrie, that the change in density, the conditions being the same, would be proportional to the density.

At the blowing pressure of maximum efficiency the value of u in equation (1) is constant and as the frequency is the same, the amplitude of vibration is the same for all gases.

The energy of the sound produced would be proportional to $\frac{1}{2}\rho u^2$, and since the velocity u was constant, the energy of the sound should be proportional to the density of the gas. This was observed to be the case. The volume of sound emitted by the pipe was greater with the carbon dioxide, than with the air wave, while in the case of hydrogen it was very weak.

The curves in Fig. 5 show that at pressures from 9 cm. to 11 cm. of mercury the force was the same for the three gases, hence at

¹ Wied. Ann., New Series, XXXVI., p. 273.

² Phil. Mag., XLI., p. 405.

these pressures the amplitudes were inversely as the square roots of the densities. The less the density the greater the velocity, so that the energy of the sound produced was the same for the three gases at these pressures.

There are a number of natural phenomena that have their explanation in this relation between pressure, density and velocity of a fluid. Perhaps the best known one is the Clément effect, in which a flat disc is held against an escaping jet of air. This is also illustrated by the ball-nozzle so extensively in use. The investigations of Hallock¹ on the Clément disc show that the pressure is much decreased at the point where the velocity is greatest.

Another phenomenon is the acoustic attractions of Guthrie which Lord Kelvin² has shown to depend on this law also.

A very striking effect is the rotating resonators of Dvořák,³ the action of which has been explained by Lord Rayleigh.⁴ Still another effect is the setting of a disc across the stream-lines in a sound-wave obtained by Lord Rayleigh,⁵ and which has been used by Boys⁶ for the detection of faint sounds.

The magnitude of the force described in this paper is greater than the tendency of a disc to set across the stream-lines. An instrument designed on the plan of Boys' using small cylinders instead of a disc would probably be quite as sensitive as the one constructed by him.

PHYSICAL LABORATORY, COLUMBIA UNIVERSITY,

May 1, 1901.

¹ Science, Aug. 2, 1895.

² Phil. Mag., XLI., p. 405.

³ Pogg. Ann., CLVII., p. 42; Wied. Ann., III., p. 308.

⁴ Theory of Sound, Vol. II., p. 42.

⁵ Phil. Mag., 5th Series, Vol. XIV., p. 186.

⁶ Nature, Vol. XLII., p. 604.

